Research Scholar Details	
Name	Miss. Ramyashri Bhaiyyalal Ramteke
Mobile Number	+91-8999658936
Email id	gauriramteke@gmail.com, ramyashriramteke14@gmail.com
Category	SC
Subject	Instrumentation Engineering
Faculty	Science and Technology
Title/Research topic	Heart Rate Variability based Stress Analysis using Deep Learning
Date of RAC	14/09/17
Date of RRC	28/03/18
Institute Registration Number	2017PIN606
Research Center	Shri Guru Gobind Singhji Institute of Engineering and Technology, Vishnupuri, Nanded
Permanent address	At. Boragon khambadi, Post. Pimpalgaon Nipani, Taluka. Paoni, Dist. Bhamdara, 441903.
Residential address	DH-3, Devgiri Girls Hostel, SGGSIE&T, Vishnupuri, Nanded.
Research Guide/Supervisor Details	
Name	Dr. Vijaya R. Thool
Mobile Number	+91-9960899486
Email id	vrthool@yahoo.com, vrthool@sggs.ac.in
Designation	Associate Prof., Dept. of Instrumentation Engg.
Institute	Shri Guru Gobind Singhji Institute of Engineering and Technology, Vishnupuri, Nanded

Synopsis for Registration as Research Scholar

for

Doctoral Degree

on

Heart Rate Variability based Stress Analysis using Deep Learning

By

Ramteke Ramyashri Bhaiyyalal

Research Scholar

Supervisor

Dr. Vijaya R. Thool

Department of Instrumentation Engineering

Shri Guru Gobind Singhji Institute of Engineering and Technology,

Nanded-431606 (M.S.) India.

Heart Rate Variability based Stress Analysis using Deep Learning

Abstract: Analysis of heart rate variability (HRV) is the only non-invasive method which shows a relation between the brain and the heart. The heart is an accurate indicator of human condition and heart activity is controlled by autonomic nervous system (ANS) which has two branches sympathetic nervous system (SNS) and parasympathetic nervous system (PNS). Hence heart rate variability is a reliable reflection of the many physiological factors modulating the normal rhythm of the heart and it is the physiological phenomenon of variation in time interval between heart beats. By analyzing fluctuation in beat-to-beat periods we can separate the role played by both sympathetic and parasympathetic nervous system. HRV varies with changes in physiological, pathological and psychological factors. The HRV analysis is done in time domain and frequency domain as well as by nonlinear way. Time domain method includes parameters such as SDNN (The *RR* intervals standard deviation), RMSSD (The square root of the mean of the sum of the squares of differences between consecutive *RR* intervals) and pNN50 (NN50 count divided by the total number of all *RR* intervals) and Frequency domain features determined by calculating power spectral density of HRV and the spectral response divided into three main components that are, very low frequency (VLF) component, low frequency (LF) component and high frequency (HF) component. Poincare plot is a nonlinear method and have been evaluated in a qualitative way using their visual pattern where by the shape of the plot is categorized into functional classes and can be evaluated quantitatively through the computation of the SD indexes of the plot. Furthermore, matching of the coefficient is carried out for classification of normal and abnormal subjects.

Objectives

- To study and understand the theory as well as practical perspective in heart rate variability analysis using variety of algorithms operates on various data.
- Collection of database using BIOPAC system from clinical screening centers and different types of sources.
- To study, understand and implement the basic electrocardiogram (ECG) signal processing filters to get accurate *RR* interval time series.
- Analyzing the collected data with the help of HRV analysis methods.
- HRV feature extraction by implementing the different types of methods or algorithm in Matlab software.

- Trying to identify the effect of HRV on various categories of the subjects and comparing with healthy subjects.

- Possible early identification of cardiovascular diseases by the feature extracted from HRV analysis.

- To study and implement the different classification methods and compare the results of those for better feasibility of HRV analysis.

- Trying to make HRV analysis tool in medical practice.

Introduction

The heart is one of the most precious organs in the entire human body and it's functioning plays a very important role in our life. Today's lifestyle is so fast and stressful because of everyday work due to that heart diseases going on increasing. Heart failure (HF) is a major health problem and is on the rise all over the world. The developed nations have identified this as a major health problem. India has seen a rapid transition in its heart disease burden over the past couple of decades. With the help of heart rate variability (HRV) analysis, we can monitor the status of the heart as well as condition of autonomic nervous system (ANS). The HRV analysis is non-invasive technique [1] as it is not making any pain to the patient while acquiring the signal from body and hence this HRV analysis is the best available method to diagnose both heart and brain simultaneously.

The origin of heartbeat is located in sino-atrial (SA) node which is the natural pacemaker of the heart generating electrical impulses throughout the heart muscles for contracting both atrium and ventricles [28]. The SA node generates such impulses about 100-120 times per minute at rest. The normal heart rate in healthy individual would never be that high. This is due to continuous control of the autonomic nervous system (ANS) over the output of SA node activity. It's regulatory effect gives real heart rate (HR). In healthy subject at rest it is 72 beats per minute (*bpm*). If it is below 60 *bpm* then it's called bradycardia and above 100 *bpm* called tachycardia.

Heart rate variability (HRV) is the variation over time period between consecutive heartbeats which is dependent on the extrinsic regulation of the heart rate (HR). HRV reflects heart's ability to adapt to changing situations by detecting and quickly responding to unpredictable stimuli. HRV analysis is the ability to assess overall cardiac health and the state of the autonomic nervous system (ANS) responsible for regulating cardiac activity [2].

To understanding the status of the ANS, the HRV is useful signal. The normal variability in HR is due to autonomic neural regulation of the heart and the circulatory system. The balancing action of the sympathetic nervous system (SNS) and parasympathetic nervous system (PNS) branches of the ANS controls the HR. Increased SNS or diminished PNS activity results in cardio-acceleration. Conversely, a low SNS activity or a high PNS activity causes cardio-

deceleration [1]. The degree of variability in the HR provides information about the functioning of the nervous control on the HR and the heart's ability to respond.

Heart rate (HR) is a non-stationary signal and it's variability may shows the indication of current disease or it may warn about impending cardiac disease [7]. The indicators may be present at all the times or may occur at certain intervals of time. It is very difficult and time consuming to study. Therefore, analysis of heart rate variation has become more accepted method for evaluating the autonomic balance between sympathetic and parasympathetic nervous system [1].

The considered factors which affecting the heart rate variability (HRV) are Blood pressure, nervous system, cardiac arrhythmia, diabetes, renal failure, gender, age, drugs, smoking, alcohol, sleep, Myocardial infarction, Diabetic neuropathy, Cardiac transplantation, Myocardial dysfunction, Thyroid, Pregnancy, etc [1, 7, 9, 25].

Literature Review

The significance of relationship between autonomic nervous system and cardiovascular mortality was recognized well before Hon and Lee appreciated the clinical relevance of heart rate variability in 1965 when they noted that fetal distress was preceded by alterations in inter beat intervals before any appreciable change occurred in the heart rate itself. During the 1970s, Ewing et al. devised a number of simple bedside tests of short-term RR differences to detect autonomic neuropathy in diabetic patients. The existence of rhythm in heart rate signal was propounded in 1973. The association of higher risk of post-infarction mortality with reduced HRV was first shown by Wolf et al. in 1977. In 1981, Akselrod et al. introduced power spectral analysis of heart rate fluctuations to quantitatively evaluate beat-to-beat cardiovascular control. Around this time only, Luczak and Luring presented and established the superiority of spectral analysis method of heart rate variability measurement. Pagani established power spectral characteristics of heart rate variability for assessing sympathovagal interaction. The presence of artifacts in HRV signal affects time domain measures such as standard deviation and mean values and spectral domain measures.

The clinical importance of HRV became apparent in the late 1980s when it was confirmed that HRV was a strong and independent predictor of mortality following an acute myocardial infarction. The quality of HRV spectral analysis depends on series of accurate *RR* intervals, which further depends upon accurate and efficient detection of *R*-peaks. There are large number of *QRS* detection algorithms which has been proposed and developed since last 40 years. In the year 1893, Einthoven proposed the concept of ECG with his principles and postulated the Einthoven triangle, sine then a short of revolution in the study of functioning of heart and analysis of ECG. The evolution of advanced signal processing techniques with high computational power of contemporary computer system has enhanced ability to derive hidden information in bio-signals. In 1985, Pan and Tompkins proposed a real time *QRS* detection algorithm [15] with higher efficiency which inspired other researchers to carry out further. In 2000, Benitez proposed a new algorithm [6] QRS complex detection using hilbert transform.

Kohler B. U. et. al. discussed the various algorithms are signal derivatives and digital filters, neural network approaches and additional approaches such as adaptive filters, hidden morkov models and wavelet based QRS detection [11] in the year 2002. Silvio Cavalcanti and Enzo Belardinelli proposed that the influence of time delay in the baroreflex control of the heart activity is analyzed by using a simple mathematical model of the short-term pressure regulation [23] in 1996.

Task Force of the European Society of Cardiology and North American Society of Pacing and Electrophysiology in the year 1996 [25]. The frequency domain analyses contributed to the understanding of the autonomic background of RR interval fluctuations in the heart rate record. In the year 1986, Berger et al. proposed an efficient algorithm for the spectral analysis of HRV [19]. Lipsitz, L. A., proposed the spectral characteristics of HRV before and during the postural tilt and aging relation [12] in 1990. Rajendra Acharya proposed the methods heart rate variability analysis in both time and frequency analysis in normal subjects of various age group [17] in 2004. Wan, F., et al. in 1998 proposed time domain heart rate variability index for assessment of dynamic stress [27], he found that the proposed index is of higher selectivity in assessment of mental stress. In 2007, Nina Y. Belova, et al. proposed and developed a better approach using wavelet transform to evaluate the instantaneous changes in the HRV [14].

The nonlinear methods later used for the biomedical signals for the analysis and interpretation in around 1995. In the year 1997, proposed and developed nonlinear analysis of heart rate and respiratory dynamics. In 2001, Brennan et al. proposed and implemented the first kind of nonlinear method i. e. poincare plot analysis [13] which is very simple in nature for HRV analysis. Hang Ding et al. proposed a new heart rate variability analysis method by means of quantifying the variation nonlinear dynamic patterns [8] in the year 2007. At the same time other nonlinear method [1, 9, 20, 22] like correlation dimension analysis, detrended fluctuation analysis, largest lyapunov exponent, approximate entropy, sample entropy, fractal dimension and hurst exponent were discussed by different researchers. Later, as the development in the nonlinear methods of HRV analysis, precise algorithm were proposed and developed to detect the disease earlier and to classify the various cardiac diseases. Argyro Kampouraki et al. in the year 2006 [3], proposed the algorithm for classification of heart rate signals using support vector machine. Further various classification methods [18, 21, 24] were discussed by different researchers depending upon the percentage of accuracy.

Hypothesis

The electrocardiogram (ECG) is influenced by these three factors. Physiological factors that affect the ECG waveform are body mass index, pregnancy, sex, and age. The pathological factors are bundle branch block, coronary artery disease, electrolyte imbalances ventricular hypertrophy, acute pericarditis, etc. Along with physiological and pathological factors even psychological factors such as acute stress and chronic stress affect the ECG waveform. This work presents analysis of heart rate variability during physiological, pathological and psychological changes. By analyzing the HRV signal of different cases in Matlab using

computer, which helps the doctors for diagnostics purpose as it may gives the pre-detection of cardiac diseases.

Here trying to implement new approach and algorithm which gives more accuracy for heart rate variability analysis by studying and implementing the present (what are now available) algorithm.

Methodology

- The suitable algorithm can be developed to process the acquired bio-signal and compute diagnostically important features for health prognosis. The algorithms of heart rate variability evaluation are continuously evolving such that the extracted health information is either time independent or should require least time, which can be managed by clinical settings.

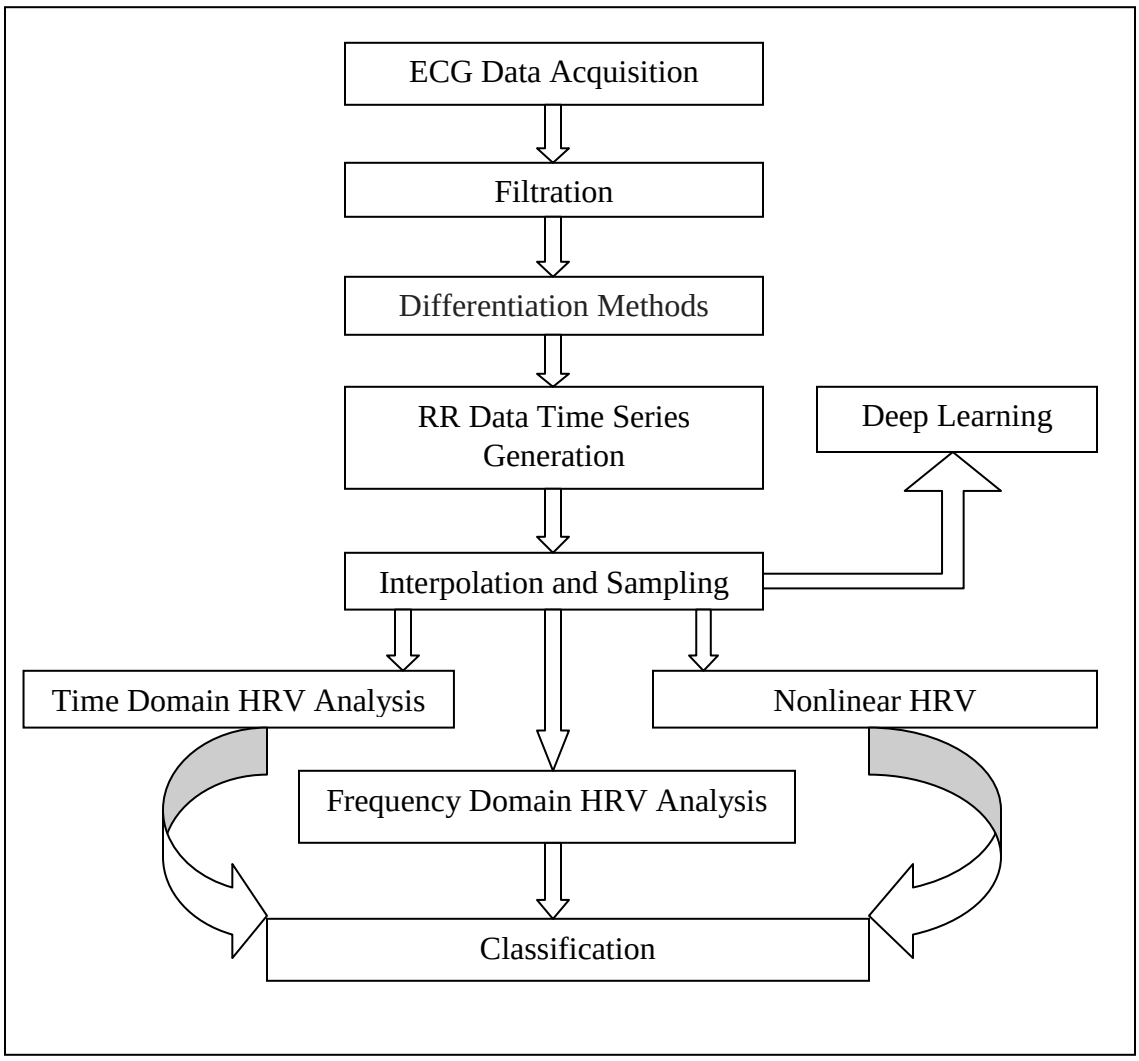

Fig.1: Block Diagram of Heart Rate Variability Analysis System

- The overall system architecture is presented in following fig.1. It includes three main phases including data analysis, feature extraction and classification. The feature extraction phase is based on the use of one of both time and frequency domain aproach.
- The BIOPAC MP 150 system will be used to ECG signal acquisition after that preprocessing of ECG signal will be done by using bandpass filter.
- Once the preprocessing completed, the preprocessed ECG signal will be used to detect *QRS*-complex by using Pan-Tompkins algorithm and wavelet transform.
- Heart rate variability (HRV) signal or *RR* interval tachogram will be generated from successive *R*-peaks.
- The HRV is unevenly time sampled signal, hence re-sampling of HRV will be carried out. There are various interpolation methods available, one of the best suitable interpolation will be applied to the acquired *RR* tachogram.
- The heart rate analysis will be carried out by linear and non-linear techniques. The linear techniques are time domain and frequency domain and non-linear techniques consists of correlation dimension analysis, detrended fluctuation analysis, largest lyapunov exponent, approximate entropy and sample entropy.
- Classification will be carried out based on the features that are extracted from previous stage. It classifies the subject as normal and abnormal.

Methods

Here some known classical methods are presented which may be used for this work and will try to adapt deep learning a new method by studying and implementing these classical methods first.

- Time Domain Methods :
  In a continuous electrocardiographic (ECG) record, each QRS complex is detected, and it is called as normal-to-normal (NN) intervals (that is all intervals between adjacent QRS complexes resulting from sinus node depolarizations), or the instantaneous heart rate is determined. Simple time domain variables that can be calculated include the mean NN interval, the mean heart rate, the difference between the longest and shortest NN interval, the difference between night and day heart rate, etc. [1, 25] Two types of time domain evaluation has been done in time domain as,

  1. Analysis by geometrical method [1]
  2. Poincare geometry [10, 26]

- Frequency Domain methods :

Power spectral density (PSD) analysis provides the basic information of how power (i.e. variance) distributes as a function of frequency [5, 25]. Methods for the calculation of PSD may be generally classified as non-parametric and parametric.

1. Non-parametric method**:** Simple algorithm (Fast Fourier Transform). Processing speed is High

2. Parametric method**:** Smoother spectral components which can be distinguished independently of preselected frequency bands. Easy post-processing of the spectrum with an automatic calculation of low and high frequency power components. Accurate estimation of PSD even on a small number of samples

3. Discrete wavelet Transform**:** The multi-resolution wavelet decomposition provides a simple hierarchical framework representation of the data. A perfect reconstruction quadrature mirror filter (QMF) bank was used to analyze frequency bands.

- Nonlinear methods :
  It is now generally recognized that these nonlinear techniques are able to describe the processes generated by biological systems in a more effective way. The parameters like correlation dimension (CD), largest lyapunov exponent (LLE), SD1/SD2 of poincare plot, ApEn, hurst exponent, fractal dimension, a slope of DFA and recurrence plots [8, 9, 19, 21].

- Deep Learning:
  Feature extraction and selection is a key process in affective state recognition. Traditional feature extraction methods are typically based on hand-designed features, which require extensive domain knowledge. Such approach is time consuming and may lose valuable certain information inherent in the raw data. Based on the research findings in neuroscience, various deep learning models, which have a strong ability in feature extraction have been developed and achieved a good performance. Deep learning is a machine learning technique that learns features and tasks directly from data. Traditional neural network contains 2 or 3 hidden layers but deep neural network contains many layers.

Possible Calculating Indices

- Time Domain: No. of Samples, Minimum (Min) and maximum (Max) value, Min/Max, Mean, Median, Variance, Standard Deviation, SDSD, RMSSD, pNN50.
- Frequency Domain: Total power, Power (n.u.), Power (%) in VLF, LF, HF, and LF/HF ratio.
- Nonlinear Methods: SD1, SD2 from poincare plot and SD1/SD2.

Software Tool

- MATLAB
- AcqKnoledge (Biopac System Software)
- Python (Possibility)

Expected Outcome

- Real time database collection for various cases like stress, pregnancy, age, gender and some for pathological factors.
- Comparison of features that will be obtained from both domains for various cases which have mentioned earlier.
- Comparison of different feature extraction methods for better results.
- Classification of parameters depends on their features value by interpreting with standardized normal values.
- Implementation using deep learning algorithm and hence comparison of traditional methods versus deep learning will be done.

References

1. Acharya, U. Rajendra, K. Paul Joseph, Natarajan Kannathal, Choo Min Lim, and Jasjit S. Suri, "Heart Rate Variability: a Review", Medical and Biological Engineering and Computing 44, no. 12 (2006): pp. 1031-1051.
2. Antonio Zaza, Federico Lombardi, "Autonomic Indexes Based on the Analysis of Heart Rate Variability: a Review from the sinus Node", Elsevier, Cardiovascular Research 50 (2001), pp. 434-442.
3. Argyro Kampouraki, George Manis, and Christophoros Nikou, "Heartbeat Time Series Classification With Support Vector Machines", IEEE Transactions on Information Technology in Biomedicine Vol. 13, No. 4, July 2009, pp. 512-518.
4. Che-Wei Lin, Jeen-Shing Wang, and Pau-Choo Chung, "Mining Physiological Conditions from Heart Rate Variability Analysis", IEEE Computational Intelligence Magazine, February 2010, pp. 50-58.
5. Cohen, Hagit, Moshe Kotler, Michael A. Matar, Zeev Kaplan, Hanoch Miodownik, and Yair Cassuto, "Power Spectral Analysis of Heart Rate Variability in Posttraumatic Stress Disorder Patients", Biological Psychiatry 41, no.5 (1997): pp. 627-629.
6. DS Benitez, PA Gaydecki, A Zaidi, AP Fitzpatrick, "A New QRS Detection Algorithm Based on the Hilbert Transform", IEEE, Computers in Cardiology 2000, 27, pp. 379-382.
7. Gulmira Kudaiberdieva, Bülent Görenek, Bilgin Timuralp, "Heart Rate Variability as a Predictor of Sudden Cardiac Death", Anatol J Cardiol 2007: 7 Suppl 1, pp. 68-70.

8. Hang Ding, Stuart Crozier, and Stephen Wilson, “A New Heart Rate Variability Analysis Method by Means of Quantifying the Variation of Nonlinear Dynamic Patterns”, IEEE Transactions on Biomedical Engineering, Vol. 54, No. 9, Septmber 2007, pp. 1590-1597.
9. Haitham M. Al-Angari and Alan V. Sahakian, “Use of Sample Entropy Approach to Study Heart Rate Variability in Obstructive Sleep Apnea Syndrome”, IEEE Transactions on Biomedical Engineering, Vol. 54, No. 10, October 2007, pp. 1900-1904.
10. Hoshi, Rosangela Akemi, Carlos Marcelo Pastre, Luiz Carlos Marques Vanderlei, and Moacir Fernandes Godoy, “Poincare Plot Indexes of Heart Rate Variability: Relationships with Other Nonlinear Variables”, Autonomic Neuroscience 177, no.2 (2013): pp. 271-274.
11. Kohlar, B. U., Hening, K. and Orglmeister, R., “The Principles of Software QRS Detection”, IEEE Engineering in Medicine and Biology, 2002, pp. 42-56.
12. Lewis A. Lipsitz, MD, Joseph Mietus, George B. Moody, and Ary L. Goldberger, MD, “Spectral Characteristics of Heart Rate Variability Before and During Postural Tilt: Relations to Aging and Risk of Syncope”, Circulation Vol 81, No 6, June 1990, pp. 1803-1810.
13. M. Brennan, M. Palaniswami, and P. Kamen, P., “Do Existing Measures of Poincare Plot Geometry Reflect Nonlinear Features of Heart Rate Variability? ”, IEEE Transactions on Biomedical Engineering, Vol. 48, No. 11, November 2001, pp. 1342-1347.
14. Nina Y. Belova, Stoyan V. Mihaylov, Boriana G. Piryova, “Wavelet transform: a Better Approach for the Evaluation of Instantanous Changes in Heart Rate Variability”, Elsvier, Autonomic Neuroscience: Basic and Clinical 131, pp. 107-122.
15. Pan, Jiapu, and Willis J. Tompkins, “A Real-Time QRS Detection Algorithm”, IEEE Transactions on Biomedical Engineering 3 (1985): pp. 230-236.
16. Payal Patil, Sonali, “Review of Heart Rate Variability Analysis and it's Measurement”, International Journal of Engineering Research & Technology (IJERT), ISSN: 2278-0181, Vol. 2 Issue 2, February- 2013, pp. 1-6.
17. Rajendra Acharya U, Kannathal N, Ong Wai Sing, Luk Yi Ping and TjiLeng Chua, “Heart Rate Analysis in Normal Subjects of Various Age Groups”, Biomedical Engineering OnLine, 2004, pp. 1-8.
18. Rajiv Ranjan Singha, Sailesh Conjeti , Rahul Banerjee, “A Comparative Evaluation of Neural Network Classifiers for Stress Level Analysis of Automotive Drivers using Physiological Signals”, Elsevier, Biomedical signal processing and control, 2013, pp. 740-754.
19. Ronald D. Berger, Solange Akselrod, David Gordon, and Richard J. Cohen, “An Efficient Algorithm for Spectral Analysis of Heart Rate Variability”, IEEE Transactions on Biomedical Engineering, Vol. BME-33, NO. 9, September 1986, pp. 900-904.
20. Rosaria Silipo, Member, IEEE, Gustavo Deco, Rossano Vergassola, and Celio Gremigni, “A Characterization of HRV’s Nonlinear Hidden Dynamics by Means of Markov Models”, IEEE Transactions on Biomedical Engineering, Vol. 46, No. 8, August 1999, pp. 978-986.

21. Roshan Joy Martis, U. Rajendra Acharya, Lim Choo Min, "ECG Beat Classification using PCA, LDA, ICA and Discrete Wavelet Transform", Elsevier, Biomedical signal processing and control, 2013, pp. 437-448.
22. Sheng Lu, Member, IEEE, Xinnian Chen, Jorgen K. Kanters, Irene C. Solomon, and Ki H.Chon, Senior Member, IEEE, "Automatic Selection of the Threshold Value r for Approximate Entropy", IEEE Transactions on Biomedical Engineering, Vol. 55, No. 8, August 2008, pp. 1966-1972.
23. Silvio Cavalcanti and Enzo Belardinelli, "Modeling of Cardiovascular Variability Using a Differential Delay Equation", IEEE Transactions on Biomedical Engineering, Vol. 43, No. 10, October 1996, pp. 982-989.
24. Stanislaw Osowski, Member, IEEE, Linh Tran Hoai, and Tomasz Markiewicz, "Support Vector Machine-Based Expert System for Reliable Heartbeat Recognition", IEEE Transactions on Biomedical Engineering, Vol. 51, No. 4, April 2004, pp. 582-589.
25. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, "Heart Rate Variability: Standards of Measurement, Physiological Interpretation, and Clinical Use", European Heart Journal (1996) 17, pp. 354-381.
26. Tayel, Mazhar B., and Eslam I. AlSaba, "Poincare Plot for Heart Rate Variability", World Academy of Science, Engineering and Technology, International Journal of Medical, Health, Biomedical, Bioengineering and Pharmaceutical Engineering 9, no. 9 (2015): pp. 708-711.
27. Wang, F., K. Sagawa and H. Inooka, "Time Domain Heart Rate Variability Index for Assessment of Dynamic Stress", Computers in Cardiology (1998) Vol. 25, pp. 97-100.
28. Rangaraj M. Rangayyan, "Biomedical Signal Analysis: a Case Study Approach", Willey Student Edition,